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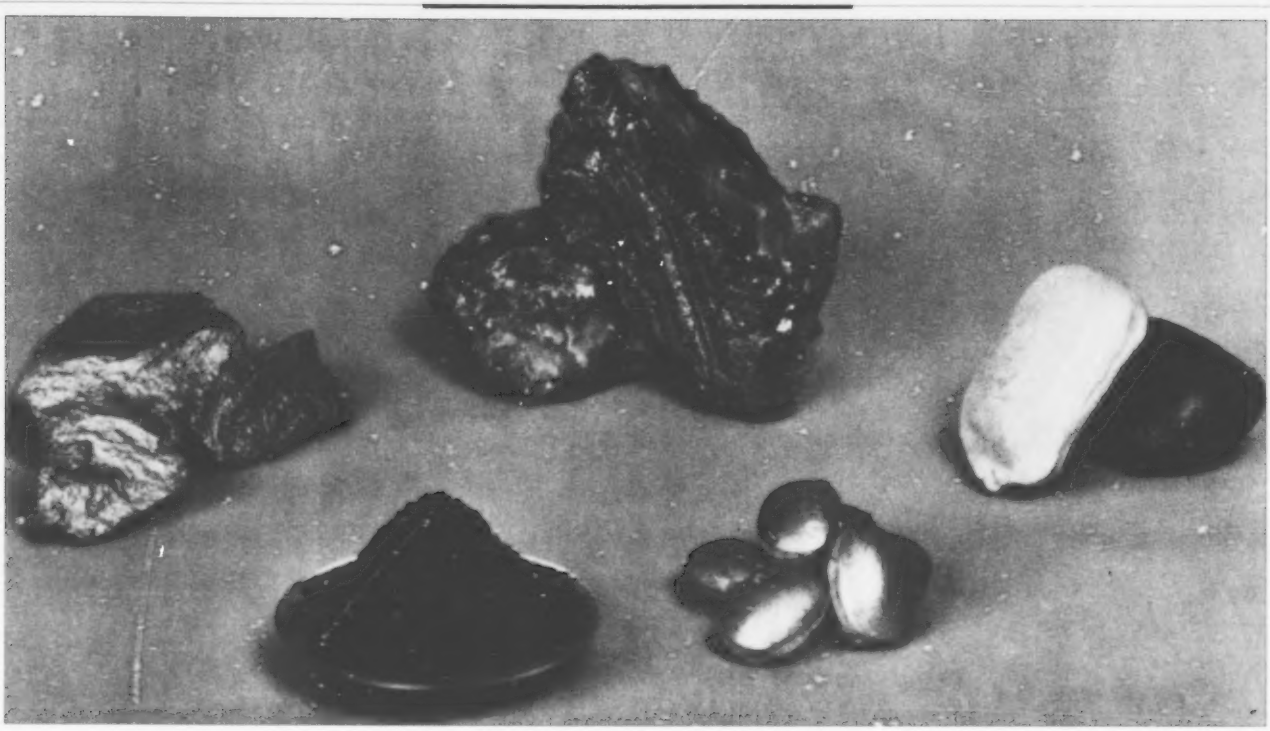

MOLYBDENUM

By John W. Blossom

1989

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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MOLYBDENUM

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October 1990

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COVER PHOTO:
Shown are processed molybdenum and molybdenum ore. The elements, clockwise from left, are ferro-molybdenum, molybdenum ore, molybdenum oxide briquets, molybdenum metal pellets, and molybdenum sulfide concentrates. (Photo is courtesy of the Cyprus Minerals Co.).

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MOLYBDENUM

By John W. Blossom

Mr. Blossom, a physical scientist/engineer with 42 years industry and Government experience, has been the commodity specialist for molybdenum since 1982. Survey and trade data were prepared by Cheryl M. Jackson, mineral data assistant; and the world production tables were prepared by Harold D. Willis, international data assistant.

Domestic and foreign molybdenum markets expanded in 1989, but mine production among market economy countries exceeded demand. Domestic producer and consumer stocks increased. U.S. mine output of molybdenum increased to 54% of world production. Reported end use consumption of molybdenum in raw materials increased. The reported U.S. consumption by end use remained about the same as in the previous year. Exports of all forms of molybdenum from the United States increased. Domestic producer stocks of molybdenum products increased to about 11 months of annual consumption.

DOMESTIC DATA COVERAGE

Domestic production data for molybdenum are developed by the Bureau of Mines by means of three separate, voluntary surveys. These surveys are Molybdenum Ore and Concentrate, Molybdenum Concentrate and Molybdenum Products, and Molybdenum Concentrates. Out of 15 operations to which surveys were sent, all responded, representing 100% of the total production shown in table 1.

PRODUCTION

Domestic mine production of molybdenum concentrate increased to a total of 139 million pounds of contained molybdenum, compared with 94 million pounds in 1988. The country's two largest suppliers, AMAX Inc. and Cyprus Minerals Co., produced sufficient material during 1989 to keep the molybdenum market stable.

TABLE 1

SALIENT MOLYBDENUM STATISTICS

(Thousand pounds of contained molybdenum and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Concentrate:					
Production	108,409	93,976	75,117	94,911	139,123
Shipments	111,936	95,006	69,868	99,738	136,097
Value	$347,812	$240,484	$179,286	$266,899	$421,427
Reported consumption	W	53,061	37,442	78,684	92,324
Imports for consumption	112	1,120	1,264	169	—
Stocks, Dec. 31: Mine and plant	9,322	8,715	15,082	r10,433	12,931
Primary products:					
Production	87,436	41,490	34,659	56,540	61,696
Shipments	73,861	57,855	40,668	45,273	40,293
Stocks, Dec. 31:	21,014	20,699	22,168	15,688	14,716
Reported consumption, by end use	33,451	31,898	32,629	38,408	38,064
World: Mine production	r216,959	204,588	196,522	p208,209	e256,658

eEstimated. pPreliminary. rRevised. W Withheld to avoid disclosing company proprietary data.

TABLE 2

PRODUCTION, SHIPMENTS, AND STOCKS OF MOLYBDENUM PRODUCTS IN THE UNITED STATES

(Thousand pounds of contained molybdenum)

	1988	1989	1988	1989
	Molybdic oxides[1]		Metal powder	
Received from other producers	7,258	W	W	W
Gross production during year	W	W	6,214	4,486
Used to make other products listed here	21,214	W	1,836	W
Net production	W	W	4,378	W
Shipments	W	W	3,731	2,028
Producer stocks, Dec. 31	10,617	W	300	274
	Other[2]		Total	
Received from other producers	r3,327	5,577	10,585	5,577
Gross production during year	50,326	57,210	56,540	61,696
Used to make other products listed here	r3,709	25,220	26,758	25,220
Net production	25,404	36,475	29,782	36,475
Shipments	41,542	38,265	45,273	40,293
Producer stocks, Dec. 31	4,771	14,442	15,688	14,716

rRevised. W Withheld to avoid disclosing company proprietary data; included with "Other."

[1] Includes technical and purified molybdic oxide and briquets.

[2] Includes ferromolybdenum, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, calcium molybdate, sodium molybdate, molybdenum metal, pellets, molybdenum pentachloride, molybdenum hexacarbonyl, and data indicated by symbol W.

CONSUMPTION AND USES

Consumption of molybdenum concentrate increased 13 million pounds in 1989. Domestic mine production of molybdenum concentrate was either roasted, exported for conversion, or purified to lubrication-grade molybdenum disulfide. The quantity of concentrate roasted domestically to produce technical-grade molybdic oxide increased over that of 1988. Oxide is the chief form of molybdenum utilized by industry, particularly steel, cast iron, and superalloy producers. However, some of the material is also converted to other molybdenum products, such

TABLE 3

U.S. REPORTED CONSUMPTION OF MOLYBDENUM, BY END USE

(Thousand pounds of contained molybdenum)

End use	Molybdic oxides	Ferro-molybdenum [1]	Ammonium and sodium molybdate	Other molybdenum materials [2]	Total [3]
1988					
Steel:					
Carbon	1,199	217	—	30	1,446
Stainless and heat resisting	7,054	442	—	162	7,657
Full alloy	6,743	2,220	—	86	9,050
High-strength, low-alloy	1,089	898	—	2	1,989
Tool	1,810	W	—	33	1,843
Cast irons	178	1,372	—	20	1,570
Superalloys	964	102	—	1,671	2,737
Alloys (excludes steels and superalloys):					
Welding and alloy hard-facing rods and materials	—	130	—	15	144
Other alloys [4]	285	103	—	181	568
Mill products made from metal powder	—	—	—	5,259	5,259
Chemicals and ceramics:					
Pigments	—	—	240	—	240
Catalysts	1,579	—	W	406	1,985
Other	8	—	1	908	917
Miscellaneous and unspecified	696	752	1,492	64	3,004
Total [3]	21,604	6,235	1,733	8,836	38,408
1989					
Steel:					
Carbon	1,016	205	—	54	1,275
Stainless and heat resisting	6,786	490	—	163	7,439
Full alloy	6,291	2,116	—	50	8,457
High-strength, low-alloy	1,030	741	—	—	1,771
Tool	1,649	W	—	9	1,658
Cast irons	W	1,703	—	20	1,723
Superalloys	1,087	123	—	2,233	3,442
Alloys (excludes steels and superalloys):					
Welding and alloy hard-facing rods and materials	—	149	—	11	160
Other alloys [4]	315	112	—	190	617
Mill products made from metal powder	—	—	—	4,228	4,228
Chemicals and ceramics:					
Pigments	W	—	W	—	W
Catalysts	2,028	—	W	395	2,424
Other	8	2	2	1,082	1,092
Miscellaneous and unspecified	581	563	2,559	72	3,775
Total [3]	20,791	6,204	2,560	8,509	38,064

W Withheld to avoid disclosing company proprietary data.

[1] Includes calcium molybdate.

[2] Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

[3] Data may not add to totals shown because of independent rounding.

[4] Includes magnetic and nonferrous alloys.

as ferromolybdenum, high-purity oxide, ammonium and sodium molybdate, and metal powder. Apparent U.S. consumption (defined as U.S. primary plus secondary production plus imports minus exports plus adjustments for Government and industry stock changes) was about 64 million pounds of molybdenum.

STOCKS

Total industry stocks, which include those of producers and consumers, increased to 33.5 million pounds of contained molybdenum. Inventories of molybdenum in concentrate at producer locations increased about 2.5 million pounds. Producer stocks of molybdenum in consumer products, such as oxide, ferromolybdenum, molybdate, metal powders, and other types, decreased about 1 million pounds. Compared with apparent consumption, yearend producer stocks of these materials represented about a 10-month supply. Domestic consumer inventories of about 6 million pounds, the same amount as at yearend 1988, representing approximately a 2-month supply as measured by average monthly reported consumption.

PRICES

The "Metals Week Dealer" (MWD) price of molybdic oxide (per pound of contained molybdenum) decreased from $3.50 in January to $2.55 at the end of December 1989. The average MWD price of oxide was $3.39, or 8 cents less than the average MWD price in 1988.

The posted producer price for molybdic oxide was $3.65 on January 1, 1989. Cyprus Minerals Co. increased its posted price to $3.97 in February and returned to a posted price of $3.65 on July 1. Both AMAX Inc. and Cyprus Minerals Co. reduced their posted prices to $3.35 in October, where the price remained to the end of 1989.

FOREIGN TRADE

Exports

Exports of molybdenum in concentrate and of oxide increased compared with those of 1988. Molybdenum concentrate exports were about 43% of domestic mine production. Approximately 98% of reported shipments of concentrate and oxides were to Belgium-Luxembourg, Canada, the Federal Republic of Germany, Japan, Mexico, the Netherlands, and the United Kingdom. The calculated molybdenum content of all exports was about 118 million pounds in 1989. Total value of exports increased from $205 million in 1988 to $327 million in 1989.

Imports

Approximately 5 million pounds of molybdenum in various forms were imported into the United States, 4.5 million pounds less than in 1988. Total value of all forms of molybdenum imported decreased from $37 million in 1988 to $30 million in 1989. In terms of both value and quantity, the major form imported was ferromolybdenum, principally from Chile and China.

TABLE 4

INDUSTRY STOCKS OF MOLYBDENUM MATERIALS, DECEMBER 31

(Thousand pounds of contained molybdenum)

	1985	1986	1987	1988	1989
Concentrate: Mine and plant	9,322	8,715	15,082	r10,433	12,931
Producers:					
Molybdic oxides[1]	16,281	16,459	W	10,617	W
Metal powder	W	W	457	300	274
Other[2]	4,733	4,240	21,711	4,771	14,442
Total[3]	21,014	20,699	22,168	15,688	14,716
Consumers:					
Molybdic oxides[1]	2,020	2,168	3,653	3,486	3,600
Ferromolybdenum[4]	597	618	554	573	514
Ammonium and sodium molybdate	47	129	76	55	41
Other[5]	1,778	1,654	1,643	1,658	1,664
Total[3]	4,441	4,569	5,925	5,772	5,818
Grand total[3]	34,777	33,983	43,175	31,893	33,465

r Revised. W Withheld to avoid disclosing company proprietary data.

[1] Includes technical and purified molybdic oxide and briquets.

[2] Includes ferromolybdenum, phosphomolybdic acid, molybdenum disulfide, molybdic acid, ammonium molybdate, sodium molybdate, calcium molybdate, molybdenum metal, pellets, molybdenum pentachloride, and molybdenum hexacarbonyl.

[3] Data may not add to totals shown because of independent rounding.

[4] Includes calcium molybdate.

[5] Includes purified molybdenum disulfide, molybdenite concentrate added directly to steel, molybdenum metal powder, molybdenum metal, pellets, and other molybdenum materials.

TABLE 5

DOMESTIC PRICE LISTINGS FOR MOLYBDENUM

(Per pound of contained metal)

	1988	1989
Merchant quotes:[1]		
Concentrate (byproducts)	$2.68	$3.17
Ferromolybdenum-export	4.27	4.31
Oxide	3.47	3.39
Producer quotes: Oxide	$3.25- 3.65	$3.35- 3.97

[1] Average.

Source: Metals Week.

WORLD REVIEW

World mine production of molybdenum was 257 million pounds, an increase of 49 million pounds from that in 1988. Canada, Chile, the U.S.S.R., and the United States accounted for more than 90% of the molybdenum produced worldwide.

Capacity

The data in table 10 are rated capacity for mines and mills as of December 31, 1989. Rated capacity is defined as the maximum quantity of product that

can be produced in a period of time on a normally sustainable long-term operating rate, based on the physical equipment of the plant and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Mine capacity for molybdenum is based on published reports, production statistics, and estimates.

Reserves

The definitions of reserves and reserve base are published in U.S. Geological Survey Circular 831, "Principles of a Resource/Reserve Classification For Minerals," which is reprinted in the introduction of the "Mineral Facts and Problems, 1985 Edition" and "Mineral Commodity Summaries, 1990."

Estimated world reserves and reserve base of molybdenum appear in table 12. Most of the world reserves of molybdenum occur in the western mountain regions of North and South America, extending from Alaska and British Columbia through the United States and Central America to the Andes Mountains of Chile. These regions, roughly bordering the eastern margin of the Pacific Basin, are also regarded as most promising for future discoveries and additions to reserves.

The United States, with a reserve base of molybdenum estimated at 11.8 billion pounds, has 47% of the world molybdenum reserve base. About 90% of U.S. reserves occurs in large porphyry or disseminated deposits mined, or anticipated to be mined, primarily for molybdenum. These deposits are located in Alaska, Colorado, Idaho, Nevada, New Mexico, and Utah. Other molybdenum sources contribute insignificantly to U.S. reserves.

Canadian reserves of primary molybdenum are located in British Columbia, including nearly 30% of the total in the Endako primary deposit. Other Canadian reserves are associated with molybdenum and copper-molybdenum porphyry deposits in British Columbia, and in relatively minor sources in Quebec and New Brunswick.

Molybdenum reserves in Central and South America are mainly in large copper porphyry deposits. Of several such deposits in Chile, the Chuquicamata and El Teniente deposits are among the world's largest and account for 85% of total molybdenum reserves in Chile. Mexico and Peru have substantial reserves. The La Caridad deposit in Mexico is a large producer. Numerous other copper porphyries that may contain recoverable quantities of molybdenum have been identified in Central and South America. Many of these deposits are actively being explored and evaluated and could add substantially to reserves in the future.

Reserves of molybdenum in the U.S.S.R. and China are estimated to be substantial, but definitive information about the current sources of supply or prospects for future development in the two countries is lacking. Copper ores are being investigated on the islands of New Guinea and Bougainville in the Southwest Pacific, but it is not known whether these contain economically recoverable molybdenum.

TABLE 6

U.S. EXPORTS OF MOLYBDENUM ORE AND CONCENTRATES (INCLUDING ROASTED AND OTHER CONCENTRATES), BY COUNTRY

(Thousand pounds of contained molybdenum and thousand dollars)

Country	1988		1989	
	Quantity	Value	Quantity	Value
Argentina	—	—	370	1,247
Australia	—	—	305	998
Austria	26	71	—	—
Belgium-Luxembourg	8,560	25,557	17,167	42,944
Brazil	192	733	437	9,814
Canada	82	355	3,579	11,033
Chile	136	52	1,307	2,679
France	—	—	80	233
Germany, Federal Republic of	5,803	13,961	5,778	13,910
India	—	—	402	1,756
Japan	7,179	18,730	8,589	25,380
Mexico	45	51	1,295	6,774
Netherlands	16,984	51,703	46,129	110,939
Sweden	2,510	6,522	248	370
United Kingdom	9,034	26,763	26,488	53,744
Other	1,256	3,742	772	1,550
Total[1]	51,807	148,237	112,946	283,371

[1] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

OUTLOOK

Capital expenditures are expected to decrease to a more normal growth rate over the next few years. Alloy and stainless steel demand is forecast to decline in 1990. Short-term molybdenum demand is expected to remain a little below the peak of 1989. Molybdenum demand appears to have ascended to a new level of usage. Molybdenum production must be adjusted to reduce inventories that have been built up in Western Europe during 1989. The long-term demand depends upon events in Eastern Europe and the U.S.S.R.'s ability to meet the needs of capital expenditures for environmental controls and to expand their manufacturing capacities.

BACKGROUND

Definitions, Grades, and Specifications

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of 95.95, and a density of 10.2 grams per cubic centimeter. The chemistry of molybdenum is complex; molybdenum exhibits oxidation states from -2 to 6, coordination num-

TABLE 7

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Thousand pounds, gross weight, and thousand dollars)

Product and country	1989 HTSUS No.	1988		1989	
		Quantity	Value	Quantity	Value
Molybdates—All:	2841.70.0000				
Argentina		(1)	2	5	67
Australia		55	159	4	14
Belgium-Luxembourg		244	867	578	1,255
Brazil		1	4	—	—
Canada		235	856	138	690
Chile		1,300	3,325	—	—
Germany, Federal Republic of		(1)	2	1	19
Japan		5,261	12,722	2,042	12,977
Korea		9	30	60	116
Mexico		4	18	16	130
Netherlands		755	2,524	187	1,288
Taiwan		5	16	—	—
United Kingdom		123	341	4	17
Venezuela		342	834	(1)	2
Other		16	128	32	372
Total[2]		8,350	21,828	3,067	16,947
Ferromolybdenum:[3]	7202.70.0000				
Belgium		—	—	40	159
Canada		31	122	65	254
Japan		49	146	12	49
Malaysia		—	—	6	20
Mexico		24	80	3	13
Singapore		—	—	22	56
Venezuela		—	—	10	38
Other		9	35	7	26
Total[2]		113	382	165	615
Molybdenum, unwrought:	8102.91.0000				
Belgium		68	472	—	—
Canada		21	140	15	119
France		5	49	4	57
Germany, Federal Republic of		36	283	13	60
India		2	13	3	14
Japan		503	3,101	297	1,709
Mexico		8	93	16	63
Netherlands		140	762	186	1,029
United Kingdom		21	158	2	25
Other		190	1,616	22	140
Total[2]		995	6,686	558	3,216
Wire:	8102.93.0000				
Argentina		5	95	1	29
Belgium-Luxembourg		18	162	31	444
Brazil		64	1,091	78	1,034
Canada		31	543	22	309
France		65	1,126	45	615
Germany, Federal Republic of		219	2,857	210	2,562
India		5	115	13	269
Italy		87	1,266	33	625
Japan		101	1,911	132	1,888

See footnotes at end of table.

bers from 4 to 8, and forms compounds with most inorganic and organic liquids. Molybdenum is a strong carbide-forming element, and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610° C; among the metallic elements, only tungsten, rhenium, osmium, and tantalum have higher melting points. Other significant physical properties of molybdenum metal are good thermal conductivity (about one-half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures, and resistance to corrosion in a wide variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures, but oxidizes readily above 500° C.

Molybdenite is the principal mineral from which molybdenum is obtained. Crude ore containing molybdenite is beneficiated to produce molybdenite concentrate. The concentrate generally contains about 90% molybdenite; the grade may be somewhat lower, particularly if produced at copper byproduct concentrating plants. Typically, "technoxide" has a molybdic-oxide content of 85% to 90%, or a minimum of 57% contained molybdenum. Other raw materials, including ferromolybdenum, purified molybdic oxide, ammonium and sodium molybdate, and molybdenum metal powder are produced from technical-grade oxide. The production of these materials is described in the next section, "Products for Trade and Industry."

The American Society for Testing and Materials (ATSM) has developed standards for the chemical composition of molybdenum oxide products (Specification A 146–64, reapproved 1979), and ferromolybdenum (Specification A 132–74, reapproved 1979). These standards specify minimums for molybdenum content and maximums for impurity content as an aid to producers and purchasers. Material marketed by the major domestic producers generally meet or exceed ASTM standards.

Products for Trade and Industry

Some commercial-grade molybdenite concentrate is treated with additional grinding and flotation steps to produce lubricant-grade 99% molybdenum disulfide.

Molybdenite concentrate is con-

TABLE 7—Continued

U.S. EXPORTS OF MOLYBDENUM PRODUCTS, BY PRODUCT AND COUNTRY

(Thousand pounds, gross weight, and thousand dollars)

Product and country	1989 HTSUS No.	1988		1989	
		Quantity	Value	Quantity	Value
Wire—Continued					
Korea		—	—	23	617
Mexico		9	271	10	226
Netherlands		1	14	(1)	15
Singapore		1	73	(1)	16
South Africa, Republic of		5	90	3	43
Spain		18	298	14	169
Sweden		26	429	31	453
Taiwan		—	—	55	278
United Kingdom		81	714	41	1,033
Other		105	1,929	9	243
Total[2]		839	12,984	751	10,868
Powder:	8102.10.0000				
Austria		—	—	44	158
Belgium-Luxembourg		529	1,934	2	12
Brazil		—	—	909	416
Canada		79	185	18	151
China		—	—	13	84
France		25	167	105	594
Germany, Federal Republic of		22	291	11	162
India		—	—	24	166
Italy		1	30	12	98
Japan		238	807	11	175
Mexico		2	8	11	73
Netherlands		24	157	29	206
Sweden		—	—	22	143
Taiwan		123	1,003	96	701
United Kingdom		223	797	70	552
Other		75	510	22	155
Total[2]		1,340	5,889	1,399	3,846
Molybdenum, wrought:	8102.92.0000				
Australia		2	34	4	64
Austria		28	292	236	258
Brazil		12	209	1	17
Canada		52	1,104	30	694
France		10	435	22	664
Germany, Federal Republic of		38	805	56	1,113
Japan		89	1,002	108	2,502
Korea		91	1469	159	483
Mexico		4	67	6	78
Netherlands		60	2,355	19	491
Singapore		—	—	(1)	4
South Africa, Republic of		1	79	5	175
Sweden		3	59	2	33
United Kingdom		50	1,120	57	1,164
Other		10	334	38	479
Total[2]		451	9,362	743	8,219

[1]Less than 1/2 unit.
[2]Data may not add to totals shown because of independent rounding.
[3]Ferromolybdenum contains about 60% to 65% molybdenum.

Source: Bureau of the Census.

verted to technical-grade 90% molybdic oxide having a maximum sulfur content of 0.1%. This oxide is the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals, and molybdenum metal powder. The technical-grade oxide is produced by roasting molybdenite concentrate in the multiple-hearth furnace at temperatures of up to 650° C. Technical-grade oxide or ferromolybdenum is used to add molybdenum to steels, cast irons, and nonferrous alloys.

Ferromolybdenum is typically produced by reduction of a mix of technical-grade oxide and iron oxide in a conventional metallothermic process, using silicon and/or aluminum as the reductant. The molybdenum content ranges from 58% to 64%.

Ammonium molybdate is produced by reacting pure molybdic oxide with ammonium hydroxide and crystallizing out the pure molybdate. Sodium and calcium molybdate are made similarly using sodium hydroxide and calcium chloride.

Molybdenum metal powder is manufactured by reducing pure molybdic oxide or ammonium molybdate with hydrogen. The purest metal powder (99.95% molybdenum minimum) is produced from ammonium molybdate. Metal powder is pressed and sintered into small metal ingots, which are converted into rod, wire, or sheet by hot rolling, swaging, or forging. Large ingots are produced by arc-casting powder under a vacuum or inert gas atmosphere.

Geology

Mineralogy.—The average crustal abundance of molybdenum is 1 to 2 parts per million (ppm). The molybdenum content of igneous rocks tends to increase with increasing silica content. Molybdenum does not occur in nature in its free or native state but is found only chemically combined with other elements. Small deposits of molybdenum-bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite, and ferrimolybdite are common but have supplied very little molybdenum. Other molybdenum minerals include chillagite, ilsemannite, koechlinite, lindgrenite, eosite, and jordisite.

Types of Deposits.—Molybdenum deposits are of five geological types: (1) porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rock, (2) contact-metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive granitic rocks, (3) quartz veins, (4) pegmatites and aplite dikes, and (5) bedded deposits in sedimentary rocks. The first three genetic-type deposits are hydrothermal in origin and, as such, represent nearly all the known molybdenum resources currently mined in the world. The remaining types do not represent a great volume of molybdenum and are economically important only when molybdenum is associated with other high-valued minerals.

Technology

Exploration.—Prospecting and exploration for molybdenum is basically the same as that for deposits of other metals. Areas generally considered favorable for molybdenite mineralization are in metallogenic provinces encompassing known occurrences of molybdenum stockworked deposits and copper-molybdenum porphyry deposits. An understanding of regional geology, mineral associations, and known patterns of molybdenite mineralization is essential to identify potential sites for field investigation. Sites for detailed study may be selected on the basis of geologic mapping of rock units and structures, geochemical analyses of sediments and soils, and ground geophysical surveys. An intensive drilling and sampling program is then required to estimate the size, grade, and continuity of the discovery. Exploration drifts may be driven into the ore body to provide more specific geologic information and bulk samples for metallurgical testing.

Mining.—Molybdenum ore is mined by underground and open pit methods, the choice of method being determined by the size, configuration, grade, and depth of the ore body.

Recycling.—Some secondary molybdenum metal is recovered in the production of alloy steels, superalloys, and the metal, but data on quantities are incomplete and inconclusive. Most of this recycled material is generated and reused directly at metal-forming or fabricating plants (runaround scrap) or shipped to plants that reclaim it (prompt industrial scrap). Very little molybdenum-containing obsolete scrap is processed for its molybdenum content. Although some molybdenum is recycled as a minor constituent of scrap alloy steels, the use of such scrap does not generally depend on its molybdenum content. An increasing quantity of molybdenum is being reclaimed from spent catalysts and chemical residues.

Byproducts and Coproducts

Tin, tungsten, and a very minor quantity of pyrite are recovered as byproducts from molybdenum ore at the Climax, CO deposit. Rhenium is extracted from flue gases and dust produced during roasting of molybdenite concentrate produced as a byproduct of copper mining.

Molybdenum is recovered as a byproduct primarily from copper ores. A very small amount is also obtained from tungsten and uranium ores. At the Sierrita Mine of Cyprus Minerals, copper and molybdenum are considered coproduct values.

TABLE 8

U.S. IMPORTS FOR CONSUMPTION OF MOLYBDENUM

(Thousand pounds and thousand dollars)

Item	1989 HTSUS No.	1988			1989		
		Gross weight	Contained molybdenum	Value	Gross weight	Contained molybdenum	Value
Molybdenum ore and concentrates, roasted	2613.10.0000	1,591	965	2,863	1,366	524	1,791
Molybdenum ore and concentrates, other	2613.90.0000	310	169	349	—	—	—
Molybdenum oxides and hydroxides	2825.70.0000	2,192	1,575	7,137	929	NA	3,298
Molydates of ammonium	2841.70.0000	1,346	804	3,262	693	398	2,106
Molybdates—all others	2841.70.5000	82	56	140	128	60	375
Molybdenum orange	3206.20.0000	2,494	NA	3,128	2,307	NA	2,858
Mixtures of inorganic compounds	3823.90.3400	1,247	906	1,348	33	28	202
Ferromolybdenum	7202.70.0000	3,704	2,369	8,504	3,108	1,702	9,062
Molybdenum powders	8102.10.0000	([1])	([1])	([1])	477	436	2,077
Molybdenum, unwrought	8102.91.1000	296	NA	3,752	133	102	2,391
Molybdenum, waste and scrap	8102.91.5000	678	NA	3,276	386	371	1,701
Molybdenum, wrought (includes bars, rods, profiles, plate, sheets, strips, foil)	8102.92.0000	119	NA	3,457	111	NA	3,311
Molybdenum wire	8102.93.0000	([2])	([2])	([2])	17	NA	553
Molybdenum other		—	—	—	6	NA	637
Total[3]		14,059	6,844	37,216	9,694	3,621	30,361

NA Not available.

[1] Data included with Molybdenum, unwrought.

[2] Data included with Molybdenum, wrought.

[3] Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

Operating Factors

The mining and milling of both primary molybdenum ore and copper ore containing molybdenum are high-tonnage operations. The largest domestic molybdenum mine has an ore-processing capacity of about 48,000 tons per day; processing capacity at the largest copper-molybdenum surface mine exceeds 100,000 tons per day of ore. Ore grade is low; therefore, open pit and underground block caving methods are required to extract ore profitably.

Costs involved in producing molybdenite concentrate vary according to mining methods used (underground or surface), physical characteristics of the ore body, and difficulty in ore beneficiation. In mining, the principal nonlabor operating expenses involve consumption of explosives, utilization of fuel, and electricity for operating equipment. Costs of ore beneficiation are dependent on use of grinding materials, flotation reagents, electricity to operate milling and concentrating equipment, and general plant maintenance. Operating variables are monitored, and adjustments are made when necessary to maximize efficiency and economy of operation.

The mining of primary molybdenum ore and disposal of ore tailings disturb land areas. Land reclamation will become increasingly necessary as mines become inactive. Copper mining that yields byproduct molybdenum entails the disturbance of significantly larger land areas. Development of new mine-mill complexes presents local socioeconomic and land-use problems. Because new potentially economic sources are likely to be found in relatively unpopulated regions with little other industry, development of a major mine can have a significant impact on established occupational patterns. Interaction between mining firms and local and state agencies has increased to ensure that mine development proceeds in as orderly and environmentally sound a manner as possible.

The conversion of molybdenite concentrate to technical-grade molybdic oxide involves roasting. Producing firms have modified roasting facilities or in-

TABLE 9

U.S. IMPORT DUTIES ON MOLYBDENUM

Type trade	HTSUS No.	Commodity description	Unit	Duties on imports	
				Most Favored Nation (MFN) percent ad valorem	Non-MFN percent ad valorem
Import/export	2613.10.0000	Molybdenum ore and concentrates, roasted	Content-kg	13.2¢/kg + 1.9%	$1.13/kg + 15%
Import/export	2613.90.0000	Molybdenum ore and concentrates, other	do.	19.8¢/kg	77.2¢/kg
Molybdenum chemicals:					
Import/export	2825.70.0000	Molybdenum oxides and hydroxides	Gross-kg	3.2%	20.5%
Import	2841.70.0000	Molybdates of ammonium	Content-kg	4.3%	29%
Export	2841.70.0000	Molybdates—all	do.	—	—
Import	2841.70.5000	Molybdates—all others	do.	3.7%	25%
Molybdenum pigments:					
Import	3206.20.0020	Molybdenum orange	Gross-kg	3.7%	25%
Export	3206.20.0000	Pigments based on chromium (moly orange, etc.)	do.	—	—
Miscellaneous chemical products:					
Import	3823.90.3400	Mix of two or more inorganic compounds of molybdenum	Gross-kg	2.8%	18%
Export	3823.30.0000	Nonagglomerated metal binders, moly, etc.	do.	—	—
Ferroalloys:					
Import	7202.70.0000	Ferromolybdenum	Content-kg	4.5%	31.5%
Molybdenum metals:					
Import	8102.10.0000	Powders	Content-kg	13.9¢/kg + 1.9%	$1.10/kg + 15%
Export	8102.10.0000	do.	Gross-kg	—	—
Import	8102.91.1000	Unwrought	Content-kg	13.9¢/kg + 1.9%	$1.10/kg + 15%
Export	8102.91.0000	Unwrought, waste and scrap	Gross-kg	—	—
Import	8102.91.5000	Waste and scrap	Content-kg	Free	Free
Import/export	8102.92.0000	Wrought	Gross-kg	6.6%	60%
Do.	8102.93.0000	Wire	do.	6.6%	60%
Do.	8102.99.0000	Other	do.	5.5%	45%

TABLE 10

MOLYBDENUM: WORLD MINE PRODUCTION, BY COUNTRY[1]

(Thousand pounds of contained molybdenum)

Country[2]	1985	1986	1987	1988[p]	1989[e]
Bulgaria[e]	420	420	440	440	420
Canada (shipments)	17,311	24,804	32,564	29,840	[3]30,102
Chile	40,541	36,555	37,349	34,231	36,500
China[e]	4,400	4,400	4,400	4,400	4,400
Iran[e]	1,100	1,100	1,100	1,100	1,100
Japan	[e]215	—	—	—	[3]—
Korea, Republic of	734	697	717	317	330
Mexico	8,292	7,386	9,700	9,824	9,900
Mongolia[e]	2,200	2,425	2,425	2,425	2,650
Niger[e]	44	44	[r]18	33	33
Peru	8,393	7,681	7,392	5,388	6,800
U.S.S.R.[e]	24,900	25,100	25,300	25,300	25,300
United States	108,409	93,976	75,117	94,911	[3]139,123
Total	216,959	204,588	196,522	208,209	256,658

[e]Estimated. [p]Preliminary. [r]Revised.

[1]Table includes data available through June 14, 1990.

[2]In addition to the countries listed, North Korea, Romania, Turkey, and Yugoslavia are believed to produce molybdenum, but output is not reported quantitatively, and available general information is inadequate to make reliable estimates of output levels.

[3]Reported figure.

Source: Bureau of Mines, Division of International Data.

TABLE 11

WORLD MOLYBDENUM ANNUAL PRODUCTION CAPACITY, DECEMBER 31, 1989

(Million pounds of contained molybdenum)

Country	Rated capacity[1]
Bulgaria	2
Canada	35
Chile	45
China	10
Iran	4
Korea, Republic of	2
Mexico	15
Mongolia	5
Niger	([2])
Peru	10
U.S.S.R.	35
United States	165
Total	328

[1]Includes capacity at operating plants as well as at plants on standby basis.

[2]Less than 1/2 unit.

TABLE 12

MOLYBDENUM RESERVES AND RESERVE BASE

(Million pounds of contained molybdenum)

	Reserves	Reserve base
North America:		
Canada	1,000	2,000
Mexico	200	500
United States	6,000	11,800
Other	—	200
South America:		
Chile	2,500	5,400
Peru	300	500
Other	—	200
Europe:		
Bulgaria	5	20
U.S.S.R.	1,000	1,500
Other	—	600
Asia:		
China	1,100	2,700
Iran	100	300
Other	—	300
Total	12,205	26,020

stalled sulfuric acid recovery equipment to reduce emissions and thereby comply with more stringent pollution restrictions. Because the molybdenum-processing industry is relatively small, raw materials and energy needs generally are not critical concerns, although increasing energy costs will add to overall production costs.

Compared to other industrial metals, molybdenum exhibits low or negligible toxicity. No significant toxic effects in human beings have been identified in the mining and processing of molybdenum materials. As an environmental trace element, molybdenum is an essential micronutrient and has been shown to be related to copper metabolism in certain animal species. Deficiencies or excesses of molybdenum can affect the normal growth and development of numerous plant and animal species.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

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